7. Words and Pictures in a Biology Textbook

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Most genre analysis in ESP has focused on the verbal texts of common genres faced by university students. The assumption seems to be that the pictures, graphs, and tables do not provide such a barrier. But in many fields the visual elements are a crucial part of learning, and they can be just as conventionalized and discipline-specific as the verbal texts. In this paper I draw on current approaches to the relations of words and pictures to consider the range of illustrations in one commonly used molecular genetics textbook.

Introduction

If you compare any current science textbook to its predecessor from thirty or forty years ago, you are likely to be struck by the vast increase in the number of illustrations. Not only are there more of them, there is a wider range of types, from photographs to diagrams to graphs and tables. This is true even at the university level, where one might expect the students to get along without the pictures, or at least without the colors. We may take the development of pictures in science texts as another example of the growing dominance of the visual over the verbal in our culture as a whole, a vast shift in our systems of representation that applies to ads, product instructions, and journalism as well as to education. Major textbooks may have as much as a fifth of their space taken up by pictures. Clearly these pictures are doing more than just illustrating, supplementing, and breaking up the dense blocks of text and attracting the attention of any reluctant readers. Learning to read them is a part of learning scientific discourse.

One educational danger is that students may think that, however hard they have to work at the written text, what the pictures say is obvious. This may be a particular problem for the many students for whom English is not their first language, but who must at some stage use textbooks in English. They may turn to the pictures as a shortcut to the meaning of the text, represented in a universal visual language. But this visual set of conventions is no more universal than the

English of the written text. It is important that we as teachers stress:

- the complex interrelation of words and pictures in these texts
- the possibility of multiple readings of images
- the different ways the images represent meanings
- the different ways the images signal degrees of reality
- the ways images change over time

Science students need to learn to be as critical in their reading of the pictures as they would be, ideally, in their reading of the words, recognizing the forms of persuasion and the assumptions that support them.

In this paper I will take my examples from Benjamin Lewin's *Genes V*, a major textbook in molecular genetics. Of course I could have chosen physics textbooks with more mathematical formulae, or engineering textbooks with more graphs, or textbooks in zoology or botany that had more photographs and maps to focus on organisms and environments; genetics cannot stand for any of these fields. But molecular genetics is a good field in which to seek examples, because it is rapidly developing new visual conventions, yet the textbooks are still fairly accessible to those of us with no training in the field. The first edition of *Genes* was first published in 1983, five years into a huge revolution in the study of genes of higher animals and plants. The version I have, from ten years later, is already the fifth edition, and is enormously changed from the first edition—that is an indication of the pace of change in this field. One reason I chose this book is that the author, Benjamin Lewin, is also the editor of the major journal in the field, and is thus familiar with a wide range of the latest images in research publications.

I have written elsewhere how a discovery in this field was popularized, from the scientific articles, to reviews, to textbooks and to articles for general readers in *Scientific American* and in newspapers. I will focus here on the chapter that deals with that discovery, "that eukaryotic genes may be interrupted." The textbook is a key part of this process of establishing the discovery, conveying some of the basic concepts, language, and imagery of the new research, but eliminating most of the detailed arguments, the evidence, and the names in the original scientific papers. The success of this particular textbook (and others like it) may someday be seen as marking the end of a genetics that focused on whole organisms and their inherited characteristics, and the triumph of a genetics based firmly on the level of molecules.

There have been two main approaches to analysis of pictures in texts; one that treats the pictures as utterances, and the other that treats the utterances as pictures. The approach that treats the pictures as utterances then analyzes them in terms of linguistic pragmatics, such as principles of relevance or co-operation. A picture of a ribosome is the equivalent of "This is a ribosome." In the approach that treats utterances as pictures, both words and pictures are kinds of signs, to be analyzed in terms of the same general semiotic processes. So the letters "r-i-b-o-s-o-m-e" and a picture of a big and a small flattened oval, one on top of the other, can both be conventional representations of an entity in the cell.

I will draw on both pragmatic and semiotic approaches, and give references for those who want to pursue either of them further. From semiotics I borrow some analyses of the relation of words and pictures, and the different ways words and pictures can represent. From pragmatics I borrow the concept of modality, as applied to both utterances and pictures. But rather than give separate reviews of these approaches (which can be found in Hodge and Kress, 1988; Kress and van Leewen, 1988; and Bastide, 1985/1992), I will go over some questions I think teachers and students should ask about the pictures in textbooks.

What is the Picture Doing Here?

The first question we need to ask is why the picture is there at all. As anyone who writes textbooks in any field knows, pictures take up space, cost money, and are an incredible hassle at every stage of production. So each picture must be there for a reason. In textbooks, as in articles, there is nearly always an explicit statement of what that reason is, in two places, in the caption above or below the picture, and in the text before a reference to the figure number. These textual references become stereotyped, using just a few verbs for instance, so we need to look more closely at what they direct us to do with the picture. Some examples are in my Table 1, which focuses on the visuals (figs. 23.15 - 23.17) in *Gene V*. (See appendix - page 125, 126)

(continued overleaf)

Table 1

Text	*caption*	*Picture*
Recall the terminology for describing the relationship between a gene and its RNA product (see Chapter 6). **Figure 23.1** shows that an interrupted gene consists of an alternating series of **exons** and **introns:**	**Figure 23.1** *Overview:* an interrupted gene consists of alternating exons and introns; the introns are removed by splicing of the RNA transcript, generating an mRNA consisting only of exon sequences. The regulatory region includes the promoter at the 5' end.	*diagram:* horizontal double helix divided into sectors; then horizontal line; then the horizontal line shortened, with parts looping out to the top; then the line with the two loops removed.
Figure 23.15 shows a zoo blot using a probe from this region.	**Figure 23.15** A zoo blot with a probe from the human Y chromosomal gene zfy identifies cross-hybriding fragments on the sex chromosomes of other mammals and birds. There is one reacting fragment on the Y chromosome and another on the X chromosome. Data kindly provided by David Page.	autoradiograph with 20 columns; names of different types of animals along the top; size in kilobases in a scale along the right
Figure 23.19 compares the structure of an immunoglobulin with its gene.	**Figure 23.19** Immunoglobin light chains and heavy chains are coded by genes whose structures (in their expressed forms) correspond with the distinct domain corresponds to an exon; introns are numbered 1-5.	diagram with a yellow horizontal band across the middle that contains a short stylized helix (the two chains); above these the short helix is paralleled by a double helix and another labelled and divided helix; below the yellow band the longer chain is paralleled by another double helix

The verbs in the text and caption suggest several uses for the pictures (see appendix). The reference, "**Figure 23.1** shows that" [followed by a noun phrase] treats the picture as a specific example of the results. In the third example, "**Figure 23.19** compares," the picture is taken as doing the comparison. In this chapter, the most common verb in the text reference is "summarizes"; the pictures are treated as economical concentrations of large amounts of data, enabling the text to refer to general rules and not to specific species or genes.

If we move from the texts to the captions, we see three ways the words direct our reading of the pictures: by providing a **gloss** for decoding specific elements or the whole picture, an **interpretation** of the meaning of the picture in disciplinary terms, or essential **background** information assumed by members of the field. The caption to Figure 23.1 is a gloss; it has three clauses corresponding to the four steps in the diagram; then it has a final detail labeling part of the diagram. The caption to 23.15 is an interpretation that tells us how to interpret these blurry lines as evidence of cross-hybridization; that is, the visual signs are given a meaning in terms of the world of nature. The first sentence of the caption to Figure 23.19 is also an interpretation that puts the message of the diagram in terms of nature; it is followed by a gloss that tells us how to read the different colored sections of the strands. This limited set of uses of pictures is more striking when we consider what pictures do not do in this textbook. They never provide proof; the **show** that is so common here always means **illustrate**, not **demonstrate**.

Why are glosses, interpretations, and background statements needed at all? Each of these pictures has, by itself, many potential meanings. Figure 23.1 could be read as being about straightening out the helix; Figure 23.15 could be read as showing differences between X and Y chromosomes; Figure 23.19 could be read as comparing the different sizes of the two chains. We are used to thinking of language as having multiple meanings, but pictures do too. The textual references and captions constrain our readings, trying to get us to choose one of the many possible interpretations.

Roland Barthes (1964/1976) described **anchorage** of the meanings of the text in the picture. But here we have pictures with many possible meanings, doubly anchored by a caption that acts as a verbal gloss, and a pointer in the text that tells us what kind of statement the text is making. Or perhaps what we have here is more like Barthes' **relay**, the back and forth relation of text and pictures as in a comic book. Here, the text directs us to the picture, which leads us back to the caption, which leads to the picture, which leads back to the text. The kinds of verbs used in the text suggest that the picture always contains the same information as the text, but in different forms. To read these different forms, students must learn visual conventions of representations and certainty to go with their learning of linguistic conventions.

How Does the Picture Refer

Genes V seems to have a narrow range of illustrations, compared to popularizations or even to other textbooks. There are few photographs, no cartoons, no maps, no portraits of scientists or pictures of equipment. But even within the narrow range of graphs and diagrams that it develops, we can find examples of quite different kinds of signs; the different pictures refer to entities in the world in quite different ways. We can look to semiotics for ways of defining these differences: **indexical** references based on a link to the referent, **iconic** references based on resemblance, and **symbolic** references based on arbitrary conventions.

Indexical signs are linked directly to the thing referred to. The lip-shaped red print on a cheek or sheet of paper is taken as a sign of a kiss because it is supposed to be the mark lipstick leaves behind. Figure 23.15 is an autoradiogram of the results of an experiment in which one bit of the human genome was used as a probe to pick out bits from the DNA of various animals. Though there are a number of steps in this procedure, a biologist thinks of the fragments as making this picture themselves - that is why it is an **auto**radiogram. The fragments have migrated in the gel according to their size, which is why there can be the scale of kilobases on the right. Then the radioactively labeled fragment binds with some sizes of bits on the gel and not others. These labeled bits then show up on the photographic paper put over it. Even the slight blurriness that accompanies this method testifies to the direct link of sign an referent. Such images were very effective in scientific articles when the discovery was first announced, because they demonstrated the results as well as reporting them. They are relatively uncommon in textbooks, where such demonstration is not always needed, and a more stylized representation may convey the information more simply.

Another way a picture can refer to something is by resembling it, as a photograph resembles a person; these are referred to as **iconic** signs. In Figure 1, the drawing of the chromosome with bands in 23.16 says *chromosome* because of the resemblance, however stylized. Throughout the book there are standard icons of DNA as helix, of mouse, fly, tRNA molecule; they are part of what assures the student of the book's accessibility. Once the resemblance is established, the image can be conventionalized and will still be read unambiguously. The pictures at the top and bottom of 23.17 come without the blurriness, and without the scales of sizes. We do not read them for particular information; we may read them as standing for "do an autoradiogram at this stage," not for the results of a particular experiment.

Finally, a **symbolic** sign can refer to a referent because of some arbitrary convention, treated as an agreement between people. The usual examples are from language, where words generally have an arbitrary relation to things. The letters used to symbolize the bases of DNA in the middle of 23.17 are purely conventional signs: **G** is not in any way shaped like Guanine, nor is **C** like Cytosine, not **T** like Thymine. The names were given for quite logical reasons I suppose, but not for visual resemblance. The letters are just the remnants of those names. A map showing a sequence as a string of letters is entirely arbitrary; there is no resemblance between the twisted coils of DNA and this neat linear and measured arrangement. The graphs through the chapter are also arbitrary—the length of the purple rectangle correlates with, say, the number of exons of a given length, but it does not resemble the exons, nor is it directly associated with them.

These three ways of referring—as an index, an icon, or a symbol—offer pretty good categories for most purposes. But in any real example one usually sees some blurring of the distinctions. For instance, the use of **CATG** for the bases is arbitrary, and so is the convention that a single strand of DNA is shown as a horizontal line with the 5' end at the left. But a biologist would argue that the linear nature of DNA is related to an important natural feature of the molecule, abstracted here but nonetheless natural—it can be seen as a sequence rather than as a ratio or a shape. The conventional way to read **CATG** is from right to left, horizontally, but that it is read is, for a biologist, a natural fact. On the other hand, an iconic or indexical sign can become conventionalized as a symbol. For instance, the same drawings of a mouse and of a fly appear rubber-stamped throughout all the diagrams of the book whenever these standard organisms for genetic experiments are referred to; when they need to show that the result of an experiment is a dead mouse, the same rubber-stamp is used upside down. This is no longer being read as a picture resembling a mouse, but as a conventionalized sign.

Signs, therefore, can be on the border between two kinds of representation, and can be conventionalized so that they are read as symbolic, not iconic. Also, any one figure can incorporate examples of different categories of signs. For instance Figures 23.15 - 23.17 include indexical, iconic, and symbolic signs, without the reader feeling that it is incomprehensibly heterogeneous.

If the distinctions between indexical, iconic, and symbolic signs blur, why insist on them? Usually my purpose is to make readers more critical of the indexical and iconic end of the scale. The power of these signs comes from their assumed naturalness, but they are only natural if one ignores the complex means used to produce them, whether by gel electrophoresis or by photography. But I think with textbooks the danger is somewhat different. Students may focus on the symbolic function of signs, missing the ways symbols are created and used, in the discipline and in their own learning. Broadly, we can see a movement in the scientific literature from indexical signs (in the first reports) to iconic (in popularizations and textbooks) to conventionalized symbols. And it may be that we see a movement in each major student's career, from icons to symbols.

How Real is it?

After these comments on the processes of representation with all pictures treated as signs, it may seem naive to ask how real the various images claim to be. But images do come with marks of greater and less certainty. Hodge and Kress (1988), and Kress and van Leeuwen (1988), have developed the idea of a visual modality, like our use of **might** or **could** or **probably** or **possibly** in language. So, for instance, the image in 23.15 with or without its caption, stakes a claim to being a statement of evidence, quite separate from the experimenter's interpretation, and is thus more certain. The drawings of an autoradiogram in 23.17, without all the grainy detail and without the scale, make no such claim. No one would consider it cause for complaint if the bands in 23.17 were not just as depicted, while we would complain if the bands in 23.15 were moved. Gilbert and Mulkay (1984) have pointed out how hard it is to suggest indefiniteness and uncertainty in pictures. One way is to reduce the images to cartoon simplicity, cutting out the details of a photograph, autoradiograph, or plot of data points.

Another element in this modality is time. The most certain images are also those tied to a moment in the past. A photograph or an autoradiogram is a unique result of a single experiment (thus the textbook's copyright acknowledgment to the researcher seems appropriate). The diagrams, on the other hand, suggest that what is shown is a timeless, general molecule and process. Figure 23.15 shows an actual series of experiments, in one image. The arrows in 23.17 show an idealized research strategy that can be repeated over and over with different molecules into the future. In these terms, there is a very strong tendency in the textbook towards the conventionalized and timeless images. Popularizations, on the other hand, stress the unique event, the lucky moment at which nature was revealed, and they may value the first images for their news value.

This takes us back to the relation of pictures to words. The words seem invariably to tie the picture to the present tense of idealized scientific fact. This is true even for historic photographs. The questions of the production of these images, which once filled paragraphs of a Methods section, are now forgotten. Images that usually have different kinds of modality are composed together on the example page into a montage in which such distinctions are lost.

Changes in Conventions of Representation

One reason to make these distinctions between types of textual links to pictures, types of referring, and levels of certainty is that they enable us to compare different ways of representing knowledge. We can see this in two kinds of comparisons, from genre to genre as the fact develops, and within one genre over time. In each case, there is a development from one end of the scale to the other.

One key change in the development between genres - research article to review article to textbook and popularization - is the change in the status of claims as facts. This change also affects the relation of words and pictures. Latour and Woolgar (1979/1986) present a scale of facticity, in which competing researchers try to push a claim up and down, especially through the use of attribution: "Watson and Crick claimed that DNA is a double helix" vs. "DNA is a double helix" vs. "the strands unwind..." (in this last instance, the point is that one does not even have to mention the helical structure; it is so much a part of the discipline). A scientific claim develops from the weakened, contingent form of its first statement and debate around it to the unmodified certainties of fact, or it gets pushed back to being a mere claim once made by someone.

I have written elsewhere about the stages of popularization of the discovery of split genes. Here I need only note that from article to textbook, we move from pictures that demonstrate (providing evidence), to pictures that illustrate (showing, summarizing, defining). We move from indexical pictures, like the autoradiogram, to iconic pictures, showing transcription at work, to more symbolic figures in which the process is reduced to the intersection of strings of letters. This visual process is a complement to the linguistic production of a fact. Even if the popularizations sometimes revive the original images produced by the thing, they now have a different meaning—they are not read in detail, but have the meaning of "historic image of split genes" along with portraits of the scientist, part of the textual museum of science. The textbook, in comparison to both the first research articles and the popularizations, excludes most of the specific, local, contingent images to generalized diagrams of processes and summaries of comparisons.

Another kind of development is in the book, *Genes*, itself. Its editions have changed in size and in the use of color. But the editions have also changed as what was a hot research area. For example, *split genes* becomes a taken-for-granted fact to be passed on so that readers can understand the latest work. Subsequent editions include more or less the same chapter, but succeeding chapters play a different role in the knowledge of the field. We can see this in comparing the types of figures used in the corresponding chapters, from electron micrographs and autoradiographs at the iconic/indexical end, to bar graphs and tables at the symbolic end. Most of the images in both editions are conventionalized diagrams of sequences. But as the field develops, the imagery becomes more and more conventionalized, less based on direct images and resemblance (which make up 16 of the 26 figures in *Genes I*), more based on purely quantitative and linear representations of disciplinary categories (which make up 14 of the 23 figures in *Genes V*).

The pedagogical effect of these changes can be seen in comparing figures with similar functions in the first and fifth editions. Both editions begin with the discovery of split genes. In *Genes I*, the background section is complemented by a reproduction of one of the original electron micrographs, and then by a diagram telling us with letters and arrows how to read the split genes in the wiggles. The caption says "one of the original electron micrographs" and thanks Philip Sharp. The drama of discovery is still part of the fact. In *Genes V*, the discovery is still mentioned. But there are no images at all of what split genes might look like. Instead the first figure in the chapter, as I have noted, is the conventionalized linear representation of the DNA. The only suggestion that this diagram is to be taken as looking at all like something in nature is the irregularity of the squiggles in the introns. As a fact is incorporated into the field, the circumstances of the discovery, the name of the discoverer, and just what the thing looked like, all become submerged. A student coming to these more conventionalized representations must work that much harder to learn the visual conventions of the discipline and to attach them to the things the discipline studies (here, transcription and translation of DNA) and the practices through which it studies these things (here, restriction enzyme fragmentation, probes, autoradiographs, sequencing). In simple terms, a student is less and less likely to have come across these conventions in secondary school, or in other science subjects; they are learned along with the written language of the specific discipline.

Implications for Teaching

Why is this important to our students? The reader may or may not share my view that science students should be taught about the social processes underlying science. But even if only interested in facilitating students' entry into the field, teachers may want to make explicit to students some of the ways of interpreting pictures. Students should always ask why the picture is there, how it refers, and how certain it is. Teachers can bring this out without doing all the semiotic and linguistic analysis I have done here. Rather than adding Roland Barthes' terminology to their troubles; teachers can just ask some simple questions. What would the book lose if this figure were deleted? What information does it add? Why choose this form of presentation, say, a diagram rather than, say, a photograph? What different captions are possible? Why is the visual placed in that particular portion in the text? What conventions do readers use to interpret it? Students might try explaining it to someone outside the discipline. Or students may just try turning it upside down - it is usually only the conventions of reading that might make this disorienting. (It is disorienting to turn a map or globe upside down because we have become familiar with the convention of North = up, and the geo-political perspective that goes with this orientation). The aim of such questioning is not to make it more difficult for students to learn conventions of a new discipline, but to raise their consciousness as to how the conventions work.

Here I have focused on just one book from one discipline. Different disciplines have different initiations into the iconography; for instance, geology starts its initiation earlier, and makes it more explicit, perhaps because geologists realize the importance of the visual in their discourse. Chemistry presents some visual conventions, such as the periodic table and the chemical bond, at the earliest level. Even within molecular genetics, there have been several different approaches to introducing the field, and each approach has a different place for the visual. This is the same problem that teachers of languages for academic purposes always have; conventions vary across disciplines. With the visual language of a discipline, as with its written language, we can start by making students aware of the differences and make explicit how they must deal with these differences.

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related to that of the probe—the probe is usually human—the probe becomes a candidate for an exon of the gene.

Such candidates are sequenced, and if they contain open reading frames, are used to isolate surrounding genomic regions. If these appear to be part of an exon, we may then seek to identify the entire gene, to isolate the corresponding cDNA or mRNA, and ultimately to identify the protein.

This approach is valuable for genes whose existence is implied by genetics, but whose nature is unknown. One example is the gene *zfy* located on the human Y chromosome. **Figure 23.15** shows a zoo blot using a probe from this region. It hybridizes specifically with sex chromosomes of mammals

Figure 23.15

A zoo blot with a probe from the human Y chromosomal gene *zfy* identifies cross-hybridizing fragments on the sex chromosomes of other mammals and birds. There is one reacting fragment on the Y chromosome and another on the X chromosome. Data kindly provided by David Page.

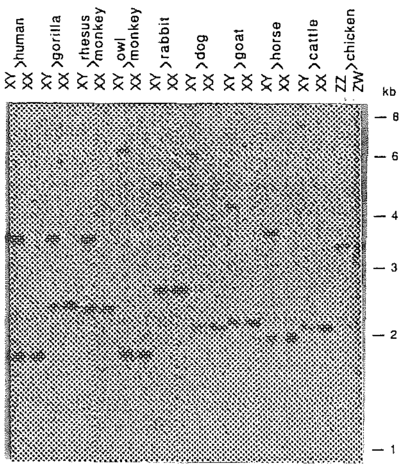
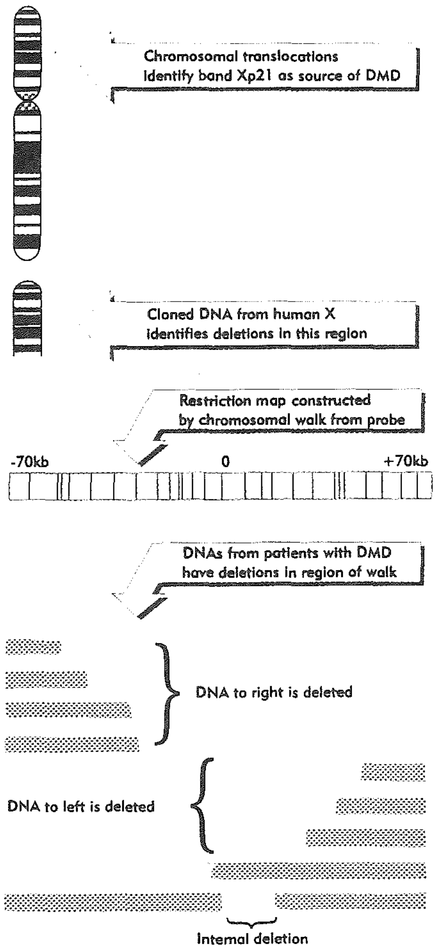


Figure 23.16

The gene involved in Duchenne muscular dystrophy has been tracked down by chromosome mapping and walking to a region in which deletions can be identified with the occurrence of the disease.



and also with other species. It contains an open reading frame, which identifies a conserved gene.

This approach is especially important when the target gene is spread out because it has many large introns. This proved to be the case with Duchenne muscular dystrophy (DMD), a degenerative disorder of muscle, which is X-linked and affects 1 in 3,500 of human male births. The steps in identifying the gene are summarized in **Figure 23.16**.

Linkage analysis localized the DMD locus to chromosomal band Xp21. Patients with the disease often have chromosomal rearrangements involving this band. By comparing the ability of X-linked DNA probes to hybridize with DNA from patients and with normal DNA, cloned fragments were obtained that correspond to the region that was rearranged or deleted in patients' DNA.

A chromosomal walk was used to construct a restriction map of the region on either side of the probe, covering a region of >100 kb. Analysis of the DNA from a series of patients identified large deletions in this region, extending in either direction. The most telling deletion is one contained entirely within the region, since this delineates a segment that must be important in gene function and indicates that the gene, or at least part of it, lies in this region.

Having now come into the region of the gene, we need to identify its exons and introns. A zoo blot identified fragments that cross-hybridize with the mouse X chromosome and with other mammalian DNAs. As summarized in **Figure 23.17**, these were scrutinized for open reading frames and the sequences typical of exon–intron junctions. Fragments that met these criteria were used as probes to identify homologous sequences in a cDNA library prepared from muscle mRNA.

The cDNA corresponding to the gene identifies an unusually large mRNA, ~14 kb. Hybridization back to the genome shows that the mRNA is represented in >60 exons, which are spread over ~2,000 kb of DNA. This makes DMD the longest gene identified; in fact, it is 10× longer than any other known gene.

Figure 23.17

The Duchene muscular dystrophy gene has been characterized by zoo blotting, cDNA hybridization, genomic hybridization, and identification of the protein.